On the Relationship Between Polarimetric Parameters and Soil Moisture

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ABSTRACT

Rough surface scattering depends on both roughness and dielectric constant of a surface. Therefore, a polarimetric measurement is useful for estimating soil moisture since we can remove the surface roughness effect using multiple scattering components from a polarimetric measurement. In this paper, we examine the relationship between polarimetric parameters and soil moisture. For example, the co-polarization ratio is independent of surface roughness to the first order of the small perturbation approximation. As surface roughness increases, it can be shown that the co-polarization ratio depends on the surface slope under the tilted Bragg approximation. The coupling of the surface roughness to the co-polarization ratio is theoretically investigated. An algorithm to compensate the surface slope effect will be discussed. We will also study other polarimetric parameters such as the average alpha angle and eigenvalues to understand their relationship with soil moisture.

I. INTRODUCTION

Soil moisture is an important parameter in understanding the global hydrologic cycle that is an endless process linking water in the atmosphere, on the continents, and in the oceans. Since the amount of water in a particular type of soil determines the dielectric constant, radar measurements are sensitive to soil moisture. Due to the limited penetration depth of a radar signal, soil moisture derived from radar measurements is related to water within several cm depth from the ground surface at the frequencies higher than L-band. Since a radar return is sensitive to both surface roughness and the dielectric constant, a polarimetric measurement is useful for estimating soil moisture by removing the effects of surface roughness.

Several empirical algorithms were reported to relate polarimetric radar responses to soil moisture [1,2,3]. These algorithms produced some successful examples; however, it was not clear that the surface roughness effect was entirely removed. Since these empirical algorithms were based on ground measurements or numerical data from a theoretical model, it is difficult to assess the validity of these algorithms. Here, we investigate the relationship between a polarimetric measurement and soil moisture systematically.

In this paper, we first discuss two polarimetric parameters related to soil moisture. Then, the sensitivity of these parameters to surface roughness is examined using the tilted Bragg method. Finally, we conclude this paper by proposing a promising soil moisture algorithm.

II. CO-POLARIZATION RATIO AND AVERAGE ALPHA ANGLE

In order to relate the polarimetric backscattering cross sections (σ_{hhhh}, σ_{vvvv}, and σ_{hvhv}) to soil moisture, we start with the expressions of the polarimetric cross sections in terms of the dielectric constant and the roughness of a scattering surface. First, we examine backscattering cross sections under the first order small perturbation approximation given by

$$\sigma_{hhhh} \approx \left|\alpha_{hh}(\varepsilon,\theta)\right|^2 F(\lambda,\theta,h_{rms}) \qquad (1)$$

$$\sigma_{vvvv} \approx \left|\alpha_{vv}(\varepsilon,\theta)\right|^2 F(\lambda,\theta,h_{rms}) \qquad (2)$$

$$\sigma_{hvhv} \approx 0 \qquad (3)$$

where

$$|\alpha_{hh}| = \left| \frac{1-\varepsilon}{\left(\cos\theta + \sqrt{\varepsilon - \sin^2\theta}\right)^2} \right| \tag{4}$$

$$|\alpha_{vv}| = \left| (\varepsilon - 1) \frac{\left[\sin^2\theta - \varepsilon\left(1+\sin^2\theta\right)\right]}{\left(\varepsilon\cos\theta + \sqrt{\varepsilon - \sin^2\theta}\right)^2} \right| \tag{5}$$

and ε is the dielectric constant, θ is the incidence angle, λ is the wavelength, and h_{rms} is the rms roughness. Notice that the surface roughness effect as shown in $F(\lambda,\theta,h_{rms})$ is independent of polarization as evidenced from equations (1) and (2). Therefore, the co-polarization ratio does not depend on the surface roughness. This is particularly true for longer radar wavelengths and at larger incidence angles since the small perturbation method is valid under these conditions. The co-polarization ratio is given by

$$\frac{\sigma_{vvvv}}{\sigma_{hhhh}} = \frac{|\alpha_{vv}(\varepsilon,\theta)|^2}{|\alpha_{hh}(\varepsilon,\theta)|^2} \tag{6}$$

From equation (6), one can estimate the dielectric constant using a polarimetric measurement. Under the same approximation, the average alpha angle (α) can be expressed as

$$\alpha = \cos^{-1}\left[\frac{1}{\sqrt{2}} \frac{1}{\sqrt{1+\dfrac{\sigma_{hhhh}}{\sigma_{vvvv}}}} \left(1 + \sqrt{\frac{\sigma_{hhhh}}{\sigma_{vvvv}}}\right) \right] \tag{7}$$

Since the surface scattering condition satisfies

$$\sigma_{vvvv} \geq \sigma_{hhhh} \tag{8}$$

the average alpha angle is between 0 and 45 degrees. From (7), it is obvious that α is a function of the co-polarization ratio only. Therefore, α is another polarimetric parameter closely related to soil moisture.

III. CO-POLARIZATION RATIO UNDER THE TILTED BRAGG APPROXIMATION

One way to reduce the limitation of the small perturbation method is to implement the two scale approximation [5]. Specifically, using the tilted Bragg component, the co-polarization ratio can be written as

$$\frac{\sigma_{vvvv}}{\sigma_{hhhh}} \approx \frac{\left[1 - \dfrac{2\langle h_y^2\rangle}{\sin^2\theta}\right]|\alpha_{vv}|^2 + \dfrac{2\langle h_y^2\rangle}{\sin^2\theta}|\alpha_{hh}||\alpha_{vv}|}{\left[1 - \dfrac{2\langle h_y^2\rangle}{\sin^2\theta}\right]|\alpha_{hh}|^2 + \dfrac{2\langle h_y^2\rangle}{\sin^2\theta}|\alpha_{hh}||\alpha_{vv}|} \tag{9}$$

where h_y is the azimuth slope. It is important to understand the meaning of the azimuth slope. Under the two scale approximation, the azimuth slope variance $\langle h_y^2\rangle$ is the variance of azimuth slopes of 2 – 3 λ surface patches within a pixel. Therefore, the azimuth slope variance includes the frequency dependence.

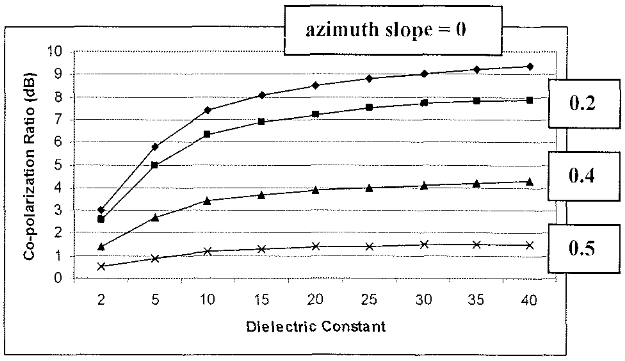

Fig. 1. Co-polarization ratio ($\sigma_{vvvv}/\sigma_{hhhh}$) for various dielectric constants and azimuth slopes (0, 0.2, 0.4, and 0.5) at 50 degrees incidence angle.

As shown in figure 1, the co-polarization ratio becomes smaller as the azimuth slope (roughness) increases. This is clearly true based on many experimental data. In order to estimate soil moisture using equation (9), it is necessary to know the azimuth slope information. We propose to derive the azimuth slope from a full polarimetric measurement using the method shown in [6]. This proposed method will be tested using ground measurements and NASA/JPL AIRSAR data.

IV. CONCLUSIONS

In this paper, we studied the relationship between two polarimetric parameters and soil moisture. Under the first order small perturbation method, both parameters depend only on dielectric constant. However, unlike the first order small perturbation method, the tilted Bragg method showed the roughness effect on the co-polarization ratio. For a rougher surface, the co-polarization ratio becomes smaller. In order to estimate soil moisture using the co-polarization ratio under the tilted Bragg method, it is necessary to know the azimuth slope variance. Here, we proposed to use a method by Lee [6] to derive the azimuth slope from a fully polarimetric measurement. This proposed method will be verified using ground measurements and NASA/JPL AIRSAR data.

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REFERENCES

[1] Y. Oh, K. Sarabandi, F. T. Ulaby, "An empirical model and an inversion technique for radar scattering from bare soil surfaces," IEEE Trans. Geosci. Remote Sens., Vol. 30, No. 2, pp. 370-381, 1992.

[2] P. C. Dubois, J. van Zyl, and T. Engman, "Measuring soil moisture with imaging radars," IEEE Trans. Geosci. Remote Sens., Vol. 33, No. 4, pp. 915-926, 1995.

[3] J. Shi, J. Wang, A. Y. Hsu, P. E. O'Neill, E. T. Engman, "Estimation of bare surface soil moisture and surface roughness parameter using L-band SAR image data," IEEE Trans. Geosci. Remote Sens., Vol. 35, No. 5, pp. 1254-1266, 1997.

[4] J. S. Lee, M. R. Grunes, T. L. Ainsworth, L. Du, D. L. Schuler, and S. R. Cloude, "Unsupervised classification using polarimetric decomposition and the complex Wishart classifier," IEEE Trans. Geosci. Remote Sens., Vol. 37, No. 5, pp. 2249-2258, 1999.

[5] Y. Kim and E. Rodriguez, "Comparison of the unified perturbation method with the two-scale expansion," IEEE Trans. Geosci. Remote Sens., Vol. 30, No. 3, pp. 510-515, 1992.

[6] J. Lee, D. L. Schuler, T. L. Ainsworth, E. Krogager, D. Kasilingam, and W. Boerner, "On the estimation of radar polarization orientation shifts induced by terrain slopes," IEEE Trans. Geosci. Remote Sens., Vol. 40, No. 1, pp. 30-41, 2002.